

Comparison of coincident Multiangle Imaging Spectroradiometer and Moderate Resolution Imaging Spectroradiometer aerosol optical depths over land and ocean scenes containing Aerosol Robotic Network sites

Wedad A. Abdou, David J. Diner, John V. Martonchik, Carol J. Bruegge, Ralph A. Kahn, Barbara J. Gaitley, and Kathleen A. Crean

Jet Propulsion Laboratory, California Institute of Technology, Pasadena, California, USA

Lorraine A. Remer and Brent Holben

NASA Goddard Space Flight Center, Greenbelt, Maryland, USA

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[1] The Multiangle Imaging Spectroradiometer (MISR) and the Moderate Resolution Imaging Spectroradiometer (MODIS), launched on 18 December 1999 aboard the Terra spacecraft, are making global observations of top-of-atmosphere (TOA) radiances. Aerosol optical depths and particle properties are independently retrieved from these radiances using methodologies and algorithms that make use of the instruments' corresponding designs. This paper compares instantaneous optical depths retrieved from simultaneous and collocated radiances measured by the two instruments at locations containing sites within the Aerosol Robotic Network (AERONET). A set of 318 MISR and MODIS images, obtained during the months of March, June, and September 2002 at 62 AERONET sites, were used in this study. The results show that over land, MODIS aerosol optical depths at 470 and 660 nm are larger than those retrieved from MISR by about 35% and 10% on average, respectively, when all land surface types are included in the regression. The differences decrease when coastal and desert areas are excluded. For optical depths retrieved over ocean, MISR is on average about 0.1 and 0.05 higher than MODIS in the 470 and 660 nm bands, respectively. Part of this difference is due to radiometric calibration and is reduced to about 0.01 and 0.03 when recently derived band-to-band adjustments in the MISR radiometry are incorporated. Comparisons with AERONET data show similar patterns.

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1. Introduction

[2] On 18 December 1999, NASA launched Terra, the first of a series of satellites within the Earth Observing System (EOS), a comprehensive program for monitoring the surface and atmosphere from remote sensing platforms and ground-based stations. Among the main objectives of EOS is improvement in our understanding of geophysical processes governing global changes in our planet's climate, including scattering and absorption of solar radiation by aerosols. Quantifying aerosol radiative forcing and its impact on the Earth radiative energy balance remains significantly uncertain without accurate long-term measurements of aerosol properties and their spatial and temporal variabilities. MISR and MODIS, two of five instruments aboard the Terra platform, measure aerosol optical depth, among other parameters [Diner *et al.*, 1998; Kaufman *et al.*, 1997a]. The Aerosol Robotic Network (AERONET), a ground-based aerosol monitoring network [Holben *et al.*, 1998], is an integral part of the EOS program that provides standardized aerosol products for validating the satellite data.

[3] The independent aerosol retrieval strategies and algorithms used by MISR and MODIS exploit the complementary multiangle (MISR) and multispectral (MODIS) nature of their measurements. Within a 7-min period, MISR observes the same point on Earth in nine different angles and four spectral bands. MODIS observes the same point in a single direction, but in 36 channels covering a wide spectral range. Of these, a subset of 7 channels is used for aerosol retrievals. The two instruments have stringent calibration performance requirements that are validated periodically using the onboard calibrators and vicarious calibration experiments [Bruegge *et al.*, 2002; Chrien *et al.*, 2002; Abdou *et al.*, 2002; Guenther *et al.*, 1998]. Comparisons between their retrieved aerosol optical depths and with those obtained from AERONET provide an opportunity to explore the similarities and differences between MISR and MODIS products. A motivation of this study is to explore the unique strengths of these two approaches quantitatively, with the ultimate goal of capitalizing on their collocation on the same platform to improve the aerosol products retrieved from Terra.

2. Aerosol Retrieval Strategies

2.1. MISR

[4] MISR contains nine push-broom cameras that observe the same point on Earth at nine different angles: nadir, $\pm 26.1^\circ$, $\pm 45.6^\circ$, $\pm 60.0^\circ$, and $\pm 70.5^\circ$ relative to nadir, both forward (+) and aft (−), and four spectral bands (446, 558, 672 and 866 nm). All routine operational processing of MISR is carried out at the NASA Langley Atmospheric Science Data Center (ASDC). Level 1 processing of MISR data produces radiometrically calibrated and georectified top-of-atmosphere (TOA) radiance data for all 36 channels (nine cameras \times 4 spectral bands) of the instrument. At level 2, coregistered multiangle, multispectral data on a 1.1 km \times 1.1 km Space Oblique Mercator grid are used in subsequent aerosol processing. Retrievals are performed over 16×16 arrays of these 1.1-km pixels, comprising 17.6×17.6 km “regions.” It is assumed that the atmospheric aerosols are laterally homogeneous within each region. An important component of MISR aerosol retrieval strategy is a lookup table (LUT) of precalculated radiances associated with a preselected set of aerosol models representative of those expected to be found in nature. The LUT, known as the Simulated MISR Atmospheric Radiative Transfer (SMART) data set, includes atmospheric path radiances and other radiative transfer parameters for the viewing and illuminating geometries relevant to MISR observations. During the retrieval process, mixtures of aerosols contained within the SMART data set are generated and subjected to a variety of tests in order to establish which model or set of models fit the data. For any given aerosol retrieval, it is possible that more than one aerosol model gives a satisfactory fit to the observations. MISR optical depth retrievals are summarized in a parameter called the regional mean spectral optical depth, which is an unweighted average over all successful models, that is, models satisfying the established set of retrieval tests. It is the only summarized optical depth parameter in MISR products that entirely excludes unsuccessful models. No weighting is applied to the average in order to achieve an unbiased mean. The MISR team recommends the use of this optical depth to data users, and recent versions of the aerosol product also archive this parameter under the name regional best estimate spectral optical depth.

[5] A first step in the retrieval process is to evaluate the surface contribution to the measured TOA radiances. Accordingly, two distinct aerosol algorithms are used: one for retrieving aerosol over land and the other over ocean, or dark water. The dark water retrieval utilizes the red and near-infrared channels and assumes that the water-leaving radiance is negligible in these two bands. The surface model explicitly accounts for specular reflection and whitecap contributions, and measurements acquired within 40° of the specular reflection are not used. The contributions of these effects to the TOA radiances are precalculated for various wind speeds and observation geometries and stored in the SMART lookup table. A recent refinement to the algorithm is to include green band radiances in the retrieval when the optical depths (τ) exceed 0.5, and the blue band radiances when the optical depths exceed 0.75, with weighting proportional to the optical depth. The weights increase linearly from zero at these threshold optical depths to 1.0 at $\tau = 1.5$ and 1.0 in the blue and green, respectively. The purpose of this refinement is to use as much available information as possible, but to minimize the effect of

surface radiances on the results. This recent refinement is applied to MISR data version F05-0011 and above (in this work data version F05-0012 are used).

[6] For aerosol retrievals over land, all 36 channels are used (a minimum of 20 channels are required). The surface contribution to the TOA radiances are represented in the retrieval algorithm as the sum of empirical orthogonal functions (EOFs) that are determined from the measured data. This is done within each region by subtracting the multiangle radiances of the darkest pixel (in the nadir) from the radiances of other pixels, effectively removing the atmospheric path radiance from these pixels. The residual radiances are then decomposed into EOFs which are used to model the angular reflectance of the surface contribution to the TOA radiance. Region-averaged radiances are then compared, via least squares, to the sum of the surface component and the atmospheric path radiance, the latter computed from mixtures of aerosol components contained in the SMART data set. The residuals in the comparisons are assessed using χ^2 statistical tests and all the optical depths and the associated aerosol models that meet a set of specified criteria are reported as successful retrievals. A major attribute of this algorithm is that it requires no assumption about the absolute reflectance of the land surface, since the separation of surface-leaving and path radiance contributions is achieved by taking advantage of differences in their angular signatures. Therefore there are in principle no restrictions on the type of surface over which the algorithm can be applied, as long as contrast is present in the scene so that the EOFs can be determined. Detailed descriptions of the MISR aerosol retrieval and its evolution since the start of MISR operation are given in the work of *Martonchik et al.* [1998, 2002].

5. Conclusions

[20] MISR and MODIS optical depth retrieved from 318 scenes that contain AERONET sites were compared. The results show that, over land, MODIS is biased high compared to MISR while the opposite is true over ocean. Compared with AERONET, MISR is in good agreement within the maximum of ± 0.05 or $\pm 0.2\tau$ for both land and dark water retrievals. In case of the latter, however, MISR is, on the average, ~ 0.05 and 0.025 higher than the AERONET in the blue and red bands, respectively, prior to application of a band-to-band radiometric calibration adjustment. The latest MISR radiometric calibration adjustments of the red and near-infrared bands by -3% and -1% , respectively, partly resolve the discrepancies of the ocean retrievals. Revised dust models are being generated to replace the more absorbing ones used in MISR's LUT. Those are expected to further improve the agreement between MISR and AERONET retrievals.

[21] MODIS retrievals over desert and coastal sites, where surface brightness and subpixel water contamination cause large errors, are biased high compared to AERONET. Over other inland sites MODIS is in better agreement with AERONET and most of the retrievals fall within the calculated uncertainty of $\pm 0.05 \pm 0.2\tau$. The data points available for the MODIS and AERONET comparison over ocean were too few to reach a meaningful conclusion. Remaining discrepancies between MISR and MODIS may be attributed to differences in their calibration, algorithm assumptions, or the aerosol models in the lookup tables used in the retrieval algorithms.